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AN
ESSAY

ON THE
NATURE AND CONNECTION

OF
HEAT,
ELECTRICITY,

AND
LIGHT.

By *ALEXANDER ANSTRUTHER, Esq.*

OF MADRAS,
BARRISTER AT LAW.

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1800.

ESSAY

NATURE AND CONNECTION

HEAT

REFLECTED

LIGHT

BY ALEXANDER NICHOLSON ESQ

OF MADRAS

EXAMINER AT LAW

LONDON

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P R E F A C E.

THE present age is peculiarly distinguished for assiduity and accuracy of research into the laws of nature, and by the general attention which the subject has excited.

CARRIED along by the stream, I have been sometimes drawn into these inquiries, and without aiming at a compleat acquaintance with every branch of the science, have yet endeavoured to acquire a competent knowledge of the leading facts proved, and the inferences drawn from them, in hopes to convey to my own mind a general view of the system of nature.

WITH this purpose I began to consider the nature and action of Heat, which seems

to be at present the least understood of any equally important branch of natural knowledge ; but with all the assistance of the very able disquisitions upon the subject, I could scarcely perceive any thing like a general plan in its operations. Knowing that few men can think with accuracy, until by committing their ideas to paper, they analyze and concentrate them, I sat down to examine by that test the opinions which I had formed. I found the effects disproportioned to the apparent cause ; and accordingly looked around for some other agent to whose ministry I might ascribe her works ; for the powers of nature, like her productions, never appear solitary. All her springs are combined in action, to produce that harmony which blends into unison her varied works.

LITTLE difficulty occurred in the search. Every thing pointed out electricity as the active power to whose exertions, in combination with those of heat, all these effects are ascribable. The same chain of inquiry
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led me to examine the connexion between these two forces, and between them and their common relation, light. I have given the reasons which induce me to believe, that they are three appearances of the same substance.

DISCUSSION is always beneficial to science, and the subject of this Essay is so intimately connected with the first principles of natural knowledge, that any new suggestion upon it, if supported by an appearance of reason, cannot be wholly unworthy of notice. I am therefore induced to submit my speculations to the public eye, that they may undergo the examination of others more able than myself to judge of their value, to approve or to condemn them.

THE order and arrangement of the different matters discussed, might, perhaps, have been more methodical : but I am not anxious to have it believed, that at the first view I perceived all the conclusions into which I was afterwards drawn; and I thought
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it would be more clear and satisfactory, to exhibit the chain of my inquiries in the order in which they occurred to me, that the same doubts may suggest to others the same explanation. This is not a treatise to arrange and elucidate known doctrines; it is a speculative essay.

PERHAPS the circumstances under which these sheets were composed, may afford some claim to indulgence for any errors they may be found to contain. They are the produce of the few leisure months which were given me after abandoning the active exercise of my profession at home, until I was able to resume it here; they were composed principally at sea, where I had neither sufficient books to resort to, nor the conversation of philosophical friends, to correct my mistakes.

IF the phaenomena which have given rise to the reflexions contained in this essay, can be better explained by any other chain of reasoning; or if, when canvassed by superior talents

talents and learning, objections, hid from my eyes, shall be discovered, I shall still recollect, with satisfaction, that I have exerted my abilities, such as they are, towards advancing our knowledge of nature. In a pursuit so alluring, and so interesting, our labour is its own reward.

Madras, 30th October, 1792.

colours and textures, and from my
eyes, shall be directed, I shall still rec-
lect, with satisfaction, that I have created
and adorned with my art, towards
advancing our knowledge in nature, for a
few are to beaming, and to instructing our
labour in the world.

Yours very truly

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ESSAY

ON THE NATURE AND CONNECTION

HEAT, ELECTRICITY, AND LIGHT.

UPON observing the texture of any solid body, it appears to us scarcely to be accounted for, that by any change within itself, its particles should assume the liquid form, or afterwards the gaseous or vaporous. These changes are produced by increase of heat ; by what process are they effected ?

SOLID bodies seem to be held together in that state by different causes. Of these, the principal are the mutual attraction and adaptation of the particles, which prevent any one from being moved without violent

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friction

friction against those adjoining. Secondary causes of the compact form of the body are, the attraction of cohesion, the pressure of the atmosphere or surrounding objects, and its own gravitation. Upon its assuming the liquid state, the two former causes are evidently overcome by some superior force. The particles are no longer held in close and firm contact; but the latter causes still retain them in one body, and prevent them from rising into vapor. After this change they no longer present any mutual obstruction, but glide easily past each other, without friction or collision; at the same time the temperature is diminished, or heat appears to be absorbed, and the capacity of the body for heat is proportionally increased. These effects being produced by the mere addition of heat, the explanation of the process and means employed must be sought in the nature of that substance.

THE prevalent theory upon the subject is this, that heat, or caloric, is a fluid, highly elastic, known only in combination. The

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proportions in which it enters into the composition of bodies at the same temperature are infinitely various, according to the different admission which each body presents to it from the conformation or position of its particles. As light easily penetrates through, and finds pores in the hardest substances, while many of the most loose in texture repel its entrance, so heat, intimately connected with light, finds for itself pores or entrances, the size and number of which can only be guessed at from the effect. The temperature marks the density or compression of the heat in those pores which are presented for its admission. If by a change in the form or position of the particles, those pores are enlarged or multiplied, the temperature or compression of the heat must be diminished ; and as there is more space for the whole heat, it will require a greater addition to raise it to any given increase of temperature or compression ; that is, the capacity for heat must be increased. Therefore, when a change of capacity and temperature takes place,

the cause is looked for in something which has altered the form or position of the particles, so as to open more space for the heat.

THE position or form of the particles of bodies while solid, is supposed to resist the admission of the heat into many of those pores which it otherwise might fill. Heat, considered as an elastic substance, must acquire additional elastic force by an addition of quantity in the same space. When accumulated to a certain degree, it is supposed to have overcome the cohesion of the particles of the body, and changed their position, so as to gain admission into space or pores before shut against it. Thus the temperature or compression of the heat must be diminished, and the capacity increased. The fluidity of the mass is accounted for, by assuming that the pores newly opened, are those which intervene between the particles of the body; so that each particle, minute beyond the perception of our senses, enveloped in its coat of heat, glides through the others

others without a possibility of touching them, or meeting with any obstruction in its passage.

WE observe that all bodies, in assuming the solid state, crystallize into regular figures. This can only be accounted for by supposing that the particles, from some sort of polar attraction between their corresponding extremities, are led to assume those forms. Heat, in producing fusion, certainly affects the polarity of the particles; for we find their position for transmission of light and of electricity materially changed by it. We may therefore reasonably infer that the effect of fusion is produced by destroying that polarity, or attraction of the corresponding extremities of the particles, which gives them the consistent appearance of solidity.

THE increase of size of bodies by heat, without change of form or of capacity, is not so easily explained. The heat struggling to enlarge its space, has in fact in-

creased the bulk of the mass; yet its compression or temperature is not diminished.

THE increase of bulk of water by cold, at eight degrees above the freezing point, reverses the phenomenon and increases the difficulty.

ANY cause which diminishes the cohesion of the particles, will facilitate the operation of heat in producing fusion. Thus if two bodies are mixed, having a strong mutual attraction, this may counteract and diminish the cohesive force of the particles of each; accordingly the heat, meeting with less internal resistance, produces fusion at a temperature which might not have dissolved either body separately. Such is supposed to be the process in the mixture of ice or water with salts; in solutions of metals in acids; of earths together, or with acids, or alkalis; and generally in solutions in menstrua.

BUT

BUT some bodies in combination exhibit the opposite effect. Metals in fusion combining with gas oxygen, the fluidity of both is destroyed. Many assist each other in fusion, which seem to have no tendency to unite in any state ; as metallic ores, and their fluxes. These contradictory appearances seem scarcely capable of a common explanation from any known qualities of heat alone.

THE next great change produced in bodies by increase of temperature, is evaporation, or volatilization. When the heat interposed between the particles is further increased and condensed, it is considered as making new efforts to enlarge its bounds. The body is still held together by the attraction of cohesion, the pressure of surrounding bodies, and its own gravitation. The particles below the surface are also pressed by the weight of those above them in the fluid mass. When by increased condensation, the heat has acquired sufficient

elastic force to overcome these obstacles, it expands the body into vapor.

In this operation the heat must be considered as having either penetrated into new pores of the body, or distended those it before filled. The former supposition accords best with the explanation given of the change from the solid to the fluid state. It may thence be inferred, that this second transition is effected by another change of position of the particles, or rather by a more minute division of them, and a change of the relative position of the component parts of those larger particles which were before the smallest divisions of the body*.

As evaporation takes place when the elasticity of the condensed heat is sufficient

* The application of electricity to fluids has the effect of perceptibly subdividing the particles; a further charge volatilizes the body. I shall have occasion afterwards to shew how nearly these effects of electricity are connected with those apparently produced by heat alone.

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to overcome the opposition it meets with, the less that opposition is, the sooner will the effect be produced. One obstacle is the weight of the incumbent atmosphere; the period of evaporation is accordingly proportioned to it. So the attraction of other substances, by diminishing the internal cohesion of the body, may facilitate the operations of the heat. Thus water is taken up in great quantities by atmospheric air at any temperature. This appearance exactly corresponds with the solution of solids in fluid menstua. In both cases the same changes of capacity and of temperature are perceived, as when the effects arise from heat alone. We are therefore to conclude, that the same cause, heat, produces the change in all the cases; and that the attraction of the menstruum has no other effect than to counteract the internal cohesion of the particles, which resisted the operation of the heat.

SUCH I believe to be nearly the outline of the present received theory of the nature
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and action of heat, and seems to be the necessary result of the opinion, founded upon the apparent fact, that these changes in bodies are the effects of this power alone. I proceed to investigate the detail and consequences of this system.

SECTION II.

It seems to be established, that every body, while it retains the same form, whether solid or fluid, has its capacity uniform; and the theory of heat supposes that increase of capacity upon a change of form, arises from the increased space opened for the admission of the heat. From this I was at first led to expect that the space requisite for the body, upon the change to the gaseous form, must bear a very near proportion to the new space opened for the heat, or in other words, to the increase of capacity. For as the particles of matter are incapable of filling more or less than a certain space, and as the only body apparently interposed is the heat, it would seem to follow, that
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the whole of the increased space must be filled with that fluid. So it might be supposed that in two gaseous bodies at the same temperature, and of the same bulk, the absolute heat must be reciprocally as their weight; for the density of the heat and the whole space being equal, the less of that space is filled with the body, the more must be occupied by the heat. Upon considering the fact, I was astonished to find how far these conclusions are wide of the truth.

IN the boiling of water, the steam is found to occupy, at that temperature, about 1800 times more space than the water: but the whole increase of absolute heat is about one-third; which being of the same density, cannot occupy that proportion of additional space. When a cubic inch of water is evaporated so as to occupy 1800 cubic inches of space, less than $1\frac{1}{3}$ inches are alone filled with the body and heat; there remain $1798\frac{2}{3}$ cubic inches to be accounted for.

By

By what is this enormous space occupied? Not by the expansion of either of the substances, the gaseous body or the heat; such enlargement would be contrary to all our ideas of the principles of matter. The heat in particular being of the same temperature or density, has not been expanded; the distention of the mass must therefore arise from some repulsive power existing in the compound.

THAT repulsion must either reside in the body or in the heat; or it must spring from some other source. The last appears to me to be the most probable conclusion; I ascribe the effect to electricity.

HEAT does not in any case shew a repulsive power, which cannot be clearly traced to its well known property of exciting electricity.

The gaseous body, separated by the elastic force of the heat, may be supposed to
 exert

exert a repulsive power from the superficies of each particle ; for it is clear, that no two particles in the closest body are ever in absolute contact ; but are only held together at a certain approximation, within which their mutual repulsion prevents them from encroaching. This repulsion, increased by the heat, may be supposed to produce the effect of evaporation. But what is this repulsion ? It is clear that every body, and every particle of it, contains a portion of electricity ; and as the powers of attraction and repulsion are found much more strongly in this than in any other substance, it is more consonant to the rules of philosophy to ascribe to it the whole of those effects, if possible, than to give the denser body a separate attractive and repulsive power, besides that which its electricity communicates. The least change in the electricity of the body materially affects the attractive and repulsive tendencies of the mass ; they must therefore be considered as arising wholly from this cause.

To

To give this proposition its proper strength, and to discover its consequences, it will be necessary here to mention so much of the known facts, or probable deductions, concerning the nature of electrical attractions, as applies to my present purpose.

BODIES filled with similar electricity repel each other; oppositely electrified, they are mutually attractive*. Some bodies are

* It seems unnecessary here to inquire at length into the causes of these several phaenomena of electricity. Perhaps they are in truth only different direions of the same force. Thus we may consider the creation as being filled with two electrical fluids attractive to each other, and therefore producing attraction in the bodies which they occupy; or, according to the Franklinian theory, with one fluid, whose tendency to equal dispersion produces the same attraction in bodies unequally filled with it. When a body is equally attracted on all sides, it will appear to lie at rest, or in the equilibrium of electricity. When two bodies, by being differently supplied with electricity, have a stronger mutual attraction than either has for the surrounding objects, they will shew this power in motion or active exertion. Where two bodies are in an electrical state more nearly similar,

are found to have in a very great degree, probably all possess more or less, the power of separating the electricities into vitreous and resinous, or positive and negative divisions. Thus a white and a black silk stocking or ribbon, closely pressed together, become oppositely electrical, and of course mutually attractive. The tourmalin, and many other bodies, when heated, analyze the electricities in the same manner. If the minutest fragment of a tourmalin be taken, it has its positive and negative side; so if two or ten thousand particles of silk, white and black, of similar texture with the stockings, were mixed and laid alternately in the same closeness, every contiguous black and white particle would analyze the electricity, and become mutually attractive; of course the mass must cohere. In such a mass however, as the different

similar, and become therefore less attractive mutually, than either is to the objects around, the attraction of these objects being no longer counteracted by an equal force, becomes active in the direction opposite to the body which has ceased to attract; and which will therefore seem to exert an active repulsive force.

particles

particles are equally dispersed, and presented in equal numbers to external objects, the whole must appear in the common equilibrium of electricity. This seems to me to be nearly the process of attraction between the particles, or the corresponding extremities of the particles of bodies, which gives them the cohesion of solidity.

THE excitation of electrics by friction seems to arise from the same cause; the two bodies tend to divide the electricities between them, but this tendency is not sufficiently strong to produce any powerful effects, unless by friction a greater proportion of their superficial particles are brought successively into contact. The electricities thus separated may be conveyed to other bodies, and charge them.

THERE is this difference, however, between the mutual attraction of bodies differently electrified by external causes, friction, or communicated electricity, and that of two particles or bodies, which tend to
analyze

analyze that fluid. In the former the attraction arises from the tendency to communicate electricity, to restore the equilibrium: when that is effected the attraction ceases. But the two stockings are attractive by their tendency to destroy the equilibrium. It is evident that this attraction is not compleat; it is only a tendency to keep the bodies so near as to analyze and separate the electricities. Compleat and perfect union is inconsistent with this tendency, and therefore attraction and repulsion are both necessary to it. This I take to be the cause of elasticity in solid bodies, and the origin of that repulsion which prevents their particles from coming into contact. When, therefore, I perceive this repulsion increased, so as to distend the body into vapor, I conclude that it arises from electricity, the active cause of the repulsion, not from any affection of the passive and inert particles of the grosser body.

WE find that heat has the most powerful effects in altering the electrical state of

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bodies.

bodies: All are changed by it, but no fixed principle can yet be traced in its operations. The same temperature electrifies some bodies positively, some negatively, some it leaves in the equilibrium. Bodies which do not otherwise show any strong electrical habits, become powerful electrics by heat; others, which in a moderate temperature exhibit strongly those affections, are brought by great refrigeration, or excessive heat, to the common level. These changes must be produced by an alteration in the distribution of the electricity in the particles of each body. But such an alteration may also take place without any external electrical appearance, provided the whole quantity of electricity presented to other objects continue the same.

It is some internal change in the distribution of electricity in bodies, which brings them to the gaseous state. In place of that electrical inequality of the particles by which they were retained in cohesive solidity, they became similarly electrical, and therefore

therefore repulsive. Probably each particle, having before a positive, a negative electrical extremity, now arranges the two electricities differently, inclosing the one within it, and being incircled by the other. The surfaces of all the particles become thus similarly electrical, and exhibit that repulsion which is found to exist between them in evaporation.

As heat produces evaporation through the medium and by the force of electricity, the latter power, when excited by any other cause, must have the same effect. Electricity evaporates fluids.

In retracing the effects upon the bodies apparently produced by heat alone, we may clearly distinguish this principle of electricity materially active in each. Fluidity requires sufficient repulsion to prevent the particles from touching, or tending to coalesce. Probably the same arrangement of electricity, which, when stronger, produces evaporation, takes place in non-elastic fluids,

each particle separating the electricities between its external and internal coats. The mutual repulsion arising from this tendency, presents a more probable explanation of fluidity, or of the free passage of the particles without collision, than the interposition of caloric, which is not otherwise proved to have such repulsive power.

THE particles of fluid bodies have very feebly, if at all, the power of mutually communicating heat; if nothing but heat were interposed between them, why should not its transmission be free?

To the same principle we may trace the elective attractions of heterogeneous bodies. They are found to be much affected by temperature, and therefore seem to flow from the various effects of the heat on the several electrical habits. If the tourmalin is heated upon glass, the former becomes positively electrical, the latter negatively; of course they are mutually attractive. Solutions of bodies in menstrua, and all chemical

mical combinations, probably flow from the same source. So the assistance which different bodies give to each other in fluxion, seems to arise from their different electrical states at the given temperature, producing mutual attractions, which ceases in some by the second electrical change occasioned by the fusion. The oxydation of metals, and the formation of water, shew the different effects of the heat at the respective temperatures on the electrical habits of the oxygen, and of the metal or hydrogen, creating in each case that attraction which constitutes combustion.

IN combination, it is not necessary that the whole of either body should outwardly appear electrical, in order to produce the attraction; for if one body tend to analyze the electricity strongly, or at large intervals between its particles, and the electrical divisions of the other be less strongly marked, this will be positively electrical to the negative particles of the former, and negatively

to those which are positive, and so attract both.

It generally happens in combination, that a certain temperature gives the attraction which produces the union, a greater or less destroys it; as in the solution of salts in water, the oxydation of metals, &c. This cannot, I think, be explained upon any known qualities of mere heat, otherwise than as it is found variously to excite the electricity of the bodies. The latter must, therefore, be considered as the immediate agent in these changes,

As heat produces or destroys combinations by the agency of electrical attractions, the same effects must follow from any other cause which produces the same changes in the electrical state of the bodies, and therefore gives the same electrical attractions. It is not, however, in many of these her more delicate operations and intricate arrangements, that we can imitate nature.

nature. In some we can : thus the electrical discharge corrodes, and gives the same colored rings to metals as heat ; these appear to be oxydations.

UPON the same principle I think it is, that we must account for another very conspicuous effect of electricity. Passing through oxygen and hydrogen, it combines them into water. This has generally, but I think erroneously, been ascribed to the heat of the electric spark. It takes place in the atmosphere in every cloud of vapour or shower of rain ; these appearances are always accompanied with strong electricity, and being generally without luminous ignition, must be attributed to the common attraction of matter, for the purpose of restoring the electrical equilibrium when disturbed. Electricity is here the sole agent. Heat does not appear even as a stimulus to its exertions. We find also, that an excessive degree and repetition of the electric shock, can decompose water into its original gases, which heat cannot effect.

There is therefore every reason to believe, that in combination, or decomposition, heat is only a mode, not always the most efficacious, of applying or exciting the electricity, which gives or destroys the requisite attraction.

THE formation of water is a subject which, both from the discussion it has occasioned among philosophers, and from its own importance, claims our utmost attention: and as the great changes displayed in the atmosphere present the operation of every natural cause upon a scale infinitely larger, and therefore less equivocal, than any experiments of our own, and perhaps contain powers which we are unable to imitate, and have therefore not sufficiently attended to, I was anxious to examine, whether the opinion which I had formed corresponded with those great appearances of nature. The production of vapor, rain, and thunder-storms, is so clearly reconcileable to the ideas here suggested, that it would be superfluous to trace the process

process of their formation. I was surprised, however, to find one appearance, the production of hail, incapable of explanation upon any principle which I had before perceived. The investigation of its nature, led me to observe more accurately the operation of the two great powers, heat and electricity, and to form important conclusions concerning the connexions between them.

SECTION III.

THE common theory of the origin of hail, supposes it to be merely rain collected in so high and cold a region of the air, as to assume the solid form. But I know no reason to believe, that hail-storms proceed from clouds more elevated than others which give rain. The hail which falls on high mountains is extremely small, from the thinness of the atmosphere which supplies it; but in lower grounds, hail generally contains as much water in each hail-stone as the largest rain. It is frequent in
hot

hot weather, when the air is heated, and its electrical inequalities strong and frequent; but it is seldom found to fall in winter in cold climates, when the air is cold, and electrical effects weaker. This seems to connect its origin with electrical causes, not with the permanent temperature of the air.

THE aqueous vapor, in being condensed into rain, diminishes in capacity about one-third, and in being frozen one-tenth more*. If, therefore, the whole be one instantaneous operation†, the vapor must have been about 584 degrees below the freezing point!

* This essay having been written on shipboard, where the author had not access to any books containing the accurate proportions of heat absorbed, they are here set down in round numbers; but, it is hoped, with sufficient correctness for the purpose to be answered.

† It is plain that if the vapor were not collected into a hail-stone, by the same instantaneous operation which first gives it the non-elastic form, it must, at the same temperature, be frozen in any previous appearance in the non-elastic state, in the loose shape of snow, and never could afterwards be collected into hail.

IF

If from the size of the hail-stones we conclude, that the first internal globule only is formed in the upper air, and that in its descent it meets with aqueous vapor, which it freezes around it, the calculation will be still more enormous. Let us suppose the original hail-stone to have been only one-fifth of the whole, and to have collected around it and frozen, four times its own portion of vapor; each of these portions in being condensed from the vaporous state, extricated and communicated to the mass one-third of its heat, and in being frozen one-tenth more. If these additional portions were, on the average, only at the freezing point, the original drop must have received 2336 degrees of heat, and is still frozen; it must therefore, at the beginning of its descent, have been 2336 degrees below the freezing point; and its component particles of vapor, as I have before shewn, 584 degrees lower, or 2920 degrees below the freezing point*.

But

* These calculations seem amply sufficient to establish the fact here contended for; were it necessary, large additions

But the whole heat at that temperature is only 1460 degrees.

HAIL cannot therefore owe its solid form to the elevation and general coldness of the surrounding atmosphere. It must arise from some cause, producing for the moment extraordinary refrigeration in the lower air in which the hail-stone is collected. This refrigeration is not the consequence of the vacuum formed by the collapſion of the vapor into the non-elastic ſtate: the utmoſt exhaustion of an air-pump does not diminish the heat of the remaining air above 5 or 6 degrees.

I AM inclined to believe, that the effect is to be accounted for from electricity alone.

ditions might be made to them. 1st, From the original heat of the hail-stone, is to be deducted all that which it has received from the atmosphere in its descent. 2d, If any part of its composition be supposed to be an immediate collection of oxygenous and hydrogenous air, we are to deduct from the heat the difference of capacity between aqueous vapor and these its component gases.

UPON

UPON examining the effects of electricity it appears, that heat is generated by it only in one way, by a shock or discharge *. If we charge a phial ever so highly, no heat is created. So if a conductor be used to carry off the electricity, it receives no heat. Now it is to be remarked, that in those cases there is no electricity added to the body; the conductor, if perfect, transmutes all that it receives, and the electric, in being changed, gives off as much from the one side as it receives on the other; or if any portion of electricity be supposed in those cases to be added to the conductor or phial, it is only of one species, vitreous or resinous. The only way in which we can accumulate both electricities, even momentarily, in any body, is by making it the conductor of a shock. While the charge is going through it in both directions, the body contains it in addition to its former electricities. This is also the only way in which heat can be generated by electricity; and as the

* A spark is a small shock or discharge; the interposed column of air is the electric discharged by it.

mere

mere passage of either species of that fluid along a conductor gives no heat, we are warranted in concluding that heat is generated by the accumulation of the two electricities. Hence I naturally infer, that a diminution of the electricities must diminish heat, or produce refrigeration. As I find in a hail storm extreme and sudden refrigeration, without any other visible cause, the electricity of the atmosphere being at the same time in great perturbation and rapid communication, I am led to believe that hail obtains the solid form from the cold produced by the diminution of electricity.

IN our limited sphere of action, we have not even attempted to diminish the electricities combined in any body, nor does it appear probable, that we shall even succeed to any extent in such an experiment. But in the great operations of nature, we see constant fluctuations in the distribution of these fluids ; and we can scarcely doubt that, by various ordinary occurrences, the whole

whole quantity in a cloud or column, if air, may be considerably diminished.

But it will be necessary to examine more fully the nature of electricity, in order to discover the connexion which unites so closely, so inseparably, all its effects with those of heat.

THE prevalent modern theory of electricity supposes the two appearances of it, before distinguished as vitreous and resinous, to be merely plus and minus quantities of the same fluid; at the same time it is admitted that every phenomenon may be explained, although, it is said, less simply, upon the old doctrine; while the advocates of the latter insist, that there are facts which cannot be reconciled to any other principles. It is not my intention here to enter into questions so fully and ably discussed, any further than to say, that I feel myself convinced by the arguments in favour of the old opinion. If upon that system, I can account for collateral appearances

ances of nature otherwise inexplicable, it will afford considerable support and confirmation to the doctrine. I consider electricity then as divisible into two distinct species, which may be called vitreous and resinous. My investigation of the subject has also led me to conclude, that the union of the two electricities is heat.

IN support of this opinion I observe, 1st, THAT in every accumulation of electricities there is increase of heat, and I have endeavoured to shew, that nature presents appearances of refrigeration to be accounted for only from a diminution of them.

WHEN one column of air has communicated electricity to another, or to the earth, it must, upon this hypothesis, contain a portion of the opposite electricity, before combined with that communicated, as heat, but now free and capable of exerting electrical power. If the cloud cannot be immediately supplied with an equal quantity of that electricity which it has
given

given off, the decomposition of the heat must diminish its quantity and power, or produce cold. In a hail-storm we find strong communication of electricity, and great cold existing together; this seems to point out the connexion between their causes, which I here suggest. When I consider that rain is generated in greatest quantities very near the surface of the earth, where it can receive little change of temperature in falling: that its temperature is generally equal, sometimes lower than that of the atmosphere; although its component particles of vapor, part of the same atmosphere, must have been raised more than one-third in temperature, by being condensed into the non-elastic state; and when I at the same time find that there is in every shower considerable loss of electrical equilibrium, I conclude that rain as well as hail is accompanied in its production by electrical decomposition, and consequent diminution of the heat; and that this refrigeration is counterbalanced in rain by the heat extricated in its condensation.

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THE air next the surface of the earth is daily heated, and rises, yet the upper atmosphere is always cold; what becomes of this heat? The air itself is incapable of communicating heat between its particles; the formation of vapor and precipitation of rain, instead of cooling the air must increase the heat by that extricated in their condensation. The heated air must therefore remain for ever heated and elevated, and the whole higher atmosphere become by degrees intensely hot, unless the heat could escape by decomposition into the electricities. Accordingly, after a long series of hot and dry weather, the atmosphere is always found strongly charged with free and active electricity.

2dly. ELECTRICITY is generally, if not always affected, the equilibrium is either destroyed or restored by heat. In exciting an electric by friction, we find that no electricity can be obtained, unless there is another body to impart it, or to extract it from the earth. But heat alone gives
either

either electric fluid to the body to which it is applied. Therefore these fluids must be contained in the substance conveyed to the body in the shape of heat.

THE process by which the communication of heat electrifies any body, may be explained thus: I before endeavoured to shew, that all bodies divide the electricities between their different particles. As heat is found only in combination with denser matter, I suppose that its production is the effect of the attraction of matter thus combining or connecting the electricities in alternate arrangement. The quantity of sensible heat obtained from any quantity of absolute heat, or of the electricities thrown into the body, is proportioned to the attraction and admission which it presents to them, and the compleat and perfect union in which it holds them. The degree of combination does not, however, depend upon the closeness of the approximation of the electricities; for a charged phial, an electrified bar, or any other body whose

electricities are separated widely by external means, continues to produce the same sensible heat. It is sufficient if the body continues to hold the electricities in attraction, so that each portion of the one shall still correspond to the same quantity as before of the opposite. When an increase of heat excites electricity, I conclude that the heat or electricities newly added, have arranged themselves in larger intervals, like the charging a phial, or electrifying a bar.

3dly. THE same inference may be established, by tracing the identity of the effects of friction upon heat and upon electricity.

WHEN an electric is rubbed with a proper rubber, it separates the electricities presented, retaining and conveying to other bodies that which it is best fitted to imbibe. In this operation the surface of the electric, and the rubber analyzing the electricities, and being then separated, that part of the electric communicates to the conductor
the

the electricity thus acquired, while another part of its surface is brought in contact with the rubber to perform the same. If the rubber has communication with the ground, it immediately attracts sufficient electricity to supply the continual demand of the electric.

IF a smooth glass globe be excited by the common rubber, it shows vitreous electricity; a rough globe resinous. If half the globe be smooth and half rough, each will be electrified. If a conductor be applied to both parts, and they are equally and oppositely electrical, it cannot receive or convey either electricity. Instead of two parts, let us divide the globe into infinitely small and numerous particles, having alternately opposite tendencies to attract electricity from the rubber; each particle will in passing attract its own; the result of the mixture is heat. This seems to me to be exactly the common process of the generation of heat by friction.

I HAVE described bodies as having cohesion, in consequence of their particles tending to analyze or separate the two electricities; non-electrics are those bodies which are little capable of dividing these fluids into regular distinct masses, but where each particle presented to external objects is differently electrical from the next, so as to counterbalance each other. In these each particle, when excited by friction, must, like the smooth and rough particles of glass, attract its own electricity from the rubber; accordingly the effect of the friction is heat.

To this it may be objected, that if the fluid were attracted from the rubber in the shape of heat, it must, during the process, diminish the temperature of the rubber or bodies from which it is communicated; and that if it were attracted as electricity of both kinds, it would require electric conductors.

THE objection may be answered by considering the nature of the electrics or non-conductors. Electrics are those bodies which

are capable (probably from the regular arrangement of their particles) of separating the electricities into regular distinct masses. This is, however, an unnatural and forced state of the body, and even in electrics *per se*, an addition of extraneous electricity is equally unnatural; accordingly, all electrics resist the being charged, or having their electricities separated; and the force of the electric shock is the proof and criterion of the strength of their tendency to return to the equilibrium. The application of foreign electricity having the effect of producing this regular separation of the electricities in the electric, its approach is resisted by the cohesive force of these fluids already combined in the body. But if by any means we present to it equal portions of the two electricities, these counterbalancing, and, as it were, neutralizing each other, will not create in the body any electrical tendency, and of course the reason of its repelling each singly does not arise. All bodies must in such a case become perfect conductors. This happens in the production or attraction of heat. The electricities

presented being in the same state with those in the body, balanced and neutralized, pass along without disturbing the electrical equilibrium, and therefore without resistance.

THE natural transmission of heat from one body to another is slow ; but if a superior force is mechanically created by friction, we find the heat attracted so rapidly and powerfully, and with so large a field of action, that the bodies immediately adjoining are supplied as fast as they communicate it, and experience no sensible refrigeration. This attraction, or apparent creation of heat by friction, has hitherto received no satisfactory explanation, and forms the principal or only obstacle to the admission of its existence as a substance. I resolve this effect into the attraction of its component parts, each of which is well known separately to have this quality.

4thly. It may even be maintained with reason, that heat is only known to us by effects purely electrical, attraction and repulsion, under which are ranked their various

rious

rious modes of action, elasticity, expansion, combustion, and other combinations. The difference seems therefore to be this: when the electricities are so separated, and the communication is by such bad conductors, that the attraction of each, for the material object to which it is attached, overcomes their tendency to re-unite, they are easily separable, and become free and transferrable singly. When they are so closely united, that the one cannot be wholly separated from the other by the common force of the attraction of matter, they pass from body to body in equal proportions, and although, in truth, each continues to exert electrical force, yet the minuteness of their separation leaving no outward trace of their distinct natures, and no tendency to motion being exerted by their attraction, they appear to neutralize each other as electricities, and obtain the name of heat.

5thly. WE observe so strong a coincidence in all the habits of heat and of electricity, that Philosophers have never doubted of their affinity. The generation of light,
their

their common offspring, seems alone sufficient to establish the connexion between them. I shall, in the succeeding pages, endeavour to shew, that that phænomenon perfectly accords with the explanation here suggested of their common nature.

6thly. UNLESS we adopt this theory, we shall find several appearances of these fluids which contradict the general maxims of our experience, and every idea which we can form of matter. We see heat and the two electricities, by turns start suddenly into being, or vanish without leaving a trace perceptible to our sense, or exerting any energy in proof of their existence. By admitting their identity, we bring them under the general laws of matter. Its properties may change the direction of their action, but the substance is always palpable. Two equal and opposite motions destroy each other ; hence we conclude, that motion is not a substance, but a quality of other substances, which may cease to exist without injury to the essences of the body. The electricities, when separated, are mutually attractive, and there-

therefore a motion, or tendency to motion, is produced; when they are as near as they tend to continue in the body to which they are attached, the attraction no longer produces motion; but the substances continue to exist under the name of heat.

If these reasons warrant the inference that heat is the combined effect of the two electricities, we shall find in it an explanation of many of those phænomena which I have before noticed.

UPON the change of any body from the solid to the fluid, and afterwards to the gaseous state, the capacity is increased, the temperature falls, or heat appears to be absorbed; at the same time the arrangement of the electricities is evidently changed, each particle seeming to center the whole of its attraction within itself. This in non-elastic fluids merely destroys the tendency of the particles to close and firm contact, and leaves them mutually in an electrical equilibrium or indifference, except so far as they are acted upon by the attraction of cohesion.

hesion, of which I shall presently shew the nature. The solid body when heated, not having sufficient power to retain the increased electricities in such close combination throughout, that attraction which connected the electricities of the several particles in solidity ceases to be produced. The whole attraction or combination of the electricities being thus reduced, their effect in the production of heat must undergo a similar diminution. This seems to be the reason of that increase of capacity and apparent absorption of heat, which we perceive upon the change from the solid state. When the body is volatilized, the internal attraction which held each particle together, is also destroyed, and the subdivisions exhibit mutual repulsion. The combination of the electricities thus receives a much greater diminution, and their effect as heat is proportionably more reduced than in the former change.

THUS we can obtain some insight into the nature of that combination of the electricities, which most powerfully produces
heat.

heat. I have before shewn that it does not depend upon the closeness of their approximation, nor upon their being in larger or smaller masses. It depends upon the arrangement of opposite and attractive portions of electricity alternately in every direction, without any repulsive or non-attractive surfaces ever adjoining.

HENCE it is that the general increase of bulk of bodies by heat, and increase of size of water by cold at a certain temperature, unaccompanied by a change of form, or of the arrangement of the electricities, has no effect on the capacity of the body.

UPON the same principles we may, perhaps, account for some of the most conspicuous differences in the modes and effects of combination of bodies. In some compounds the capacity is increased, in others diminished; some are fused or volatilized at a lower temperature than their components, others at a higher. Some combinations are nearly permanent, others yield to the first change of temperature; or to the attrac-

attraction of other bodies. These varieties arise from the different modes of attraction binding the bodies in union. The heterogeneous particles may tend to divide the electricities between them either partially or entirely; or they may be attractive by the one body's separating the electricities into wider and larger divisions than the other. These differences may be infinitely varied, and the effects on the combinations must be regulated by them. Thus two bodies in combination, may tend to correct the effect of the heat in electrifying each, and so their continuance in combination may be very great. The two bodies have originally only a certain power of attracting or holding in combination the electricities. If by their union the electricities are brought into more or less close combination, the temperature and capacity must be altered; and as the whole quantity and closeness of combination of the electricities, no longer bear the same proportion to the power of the bodies to contain them, the period of fusion must be proportionably accelerated or retarded.

SEC-

SECTION IV.

THE appearance of light is so intimately connected with those of heat and electricity, that no speculation upon their nature can be entitled to attention, unless it include a reasonable account of this phænomenon. I have found its appearances so perfectly to coincide with the opinions which I have above suggested, as to furnish a very strong confirmation of their truth.

It is found that all bodies are constantly emitting rays, which, when supplied in a certain copiousness, affect the eye with the sensation of light. The elasticity of the fluid, or mutual repulsion of particles of similar electricity, seem constantly exerted to effect its escape from the poison which the grosser matter throws around it. These rays I take to be in all cases particles of single electricity, not of heat.

RAYs of light are found to travel at a certain equal velocity, and calculations of
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their quantity and velocity have supposed each particle of light in a sun-beam, minute beyond our conception, to be distant about a thousand miles from its successor in the same direction. This accounts for their shewing little electrical attractive force, their velocity being too great, and their bulk too minute to allow its action upon heavier bodies.

IF a substance emits visible rays of each of the electricities, as must happen where it is rendered luminous from equal increases of each, that is from heat, their re-union in any body which stops them will re-produce heat. This re-union may, however, be prevented by making the rays pass through a medium which will transmit the one species of electrical particles, and absorb or reflect the other. Thus the rays of a common fire, collected in the focus of a concave mirror, give great heat and light. If a piece of glass be interposed, the focus exhibits great light, but no heat.

THE solar rays seem to be emanations of similar electricity, for when separated they
produce

produce effects fimilar to each other and to the whole, varying only in strength. If they confifted of oppofite electricities, any body which ftopped their courfe, however fituated or of whatever texture, muft receive equal heat from them; but in fact the air receives hardly any heat from the fun's rays, and mountains, and even elevated continents, much lefs than lower grounds. I fuppofe the difference to arife from the degrees of facility, with which different bodies can fupply the oppofite electricity, to be combined with the folar rays in the formation of heat.

As the electricity of the earth has attraction for the whole mafs of matter of which the globe confifts, the general direction of this force muft be towards the center; it muft, therefore, exift in greater quantities at the level of the fea, than in places removed above the general furface. Bodies thus fituated can, therefore, afford a fmaller fupply of this electricity to be combined with the folar rays into heat. Elevated regions, however level or extenfive, are therefore much colder than others in the fame latitude, lying lower.

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ALTHOUGH

ALTHOUGH the minuteness of particles of light prevents them from occasioning perceptible electrical sensations in the bodies upon which they fall, yet their electrical power is not inactive; it is unable to move the grosser body, but its effect on the lighter substance of the ray is very sensible. In passing from a thin to a dense medium, the rays are attracted by the latter most strongly, and are therefore refracted. Their various refrangibilities shew that this effect arises from their particular attractive tendencies, or electrical forces, not from any general gravitation of matter.

If a capillary obstacle is placed adjoining to the path of a ray, the latter, instead of being attracted to the material object, is repelled on each side, and deflected from its course. This is an effect merely electrical; it is produced thus. All bodies are more or less electrics. The ray acts like any other portion of foreign electricity, tending to charge the body by disturbing the equilibrium or natural arrangement of the electri-

electricity within it. Its approach is therefore resisted, and the ray repelled and deflected. The resistance of all surfaces to admission of light, is probably the cause of opacity, or of the absorption or reflection of light, from the multiplicity of surfaces of the particles of opaque bodies.

If a plate of one transparent medium be interposed between two others of a different density, regularly diverging; as if two plates of glass, the one a portion of a sphere, the other a plain, joined in one point, have the rest of their surfaces separated by air, and a ray be made to fall upon the plates, it will be alternately transmitted and reflected from the lower surface of the interposed medium in a regular succession of colors, according to the thickness of the interposed plate of air. If the experiment is tried with a ray of one color, it is alternately transmitted and reflected at regular increases of thickness of the interposed medium. This is according to the common laws of electricity. If a bar is electrified, or charged by

the application of foreign electricity, its electricities are separated into masses alternately vitreous and resinous, the space occupied by each, or the size of the divisions, depending upon the force of the electricity applied. A magnetic bar exhibits the same phenomenon. The plate of air, penetrated by the ray of light, represents such a bar, which is charged, or suffers a separation of its electricities by the application of the foreign electricity, the ray. If the length of the bar, or thickness of the interposed plate of air, be such that only one division of the electricity with that strength of charge can be contained in it, that will necessarily be of the same kind, vitreous or resinous, with the ray or electricity applied. A repulsion must, therefore, take place between the ray and the medium, and it will more readily pass on to another transparent medium than revert through this. If the medium be of such thickness as to admit of two divisions of the electricity, the one similar to the ray, the other opposite, the latter must be attractive to it; and therefore when the ob-

stacle

stacle of another surface, the lower plate of glass, is opposed, and the ray is also attracted by the medium in which it is moving, it is stopped in its course and reflected. The third space is as the first; the fourth as the second; and thus the alternate fits of easy transmission and reflexion arise. The rays of different colors having different electrical powers, produce various intervals or divisions of the electricities, and therefore are reflected at different thicknesses of the medium; hence the succession of colored rings from a white ray. The alternate attraction and repulsion between the body and the ray, and the consequent contraction and dilation of the former, may create the effect of vibration, to which Sir Isaac Newton attributed this, and almost every other phenomenon of the solar rays. This vibration may aid the process.

IN these cases I suppose the effect to be produced by the bodies being electrified, or having its electricity arranged in an unusual manner, by the application of extraneous

electricity. But I have before shewn, that all bodies at rest contain the electricities separate and distinct from each other, although less widely removed than when electrified; and every appearance of electricity marks it as an essential principle of its nature, to arrange itself in each body in divisions perfectly regular. Bodies even at rest may, therefore, be considered as representing an electrified bar, consisting throughout of regular divisions, alternately vitreous and resinous. This arrangement will extend as far, as there is a continuation of matter sufficiently similar in density to carry on the alternate fluctuation of electricity unbroken. Where two such bodies are so nearly in contact, as to communicate and link together the electrical chain, a certain attraction must take place between them. This is the attraction of cohesion.

ALL bodies being thus arranged in regular divisions of electricity, the next inquiry is what those divisions are. The nature of electricity will explain them.

IF

IF light be electricity, this is a generic name for many fluids, varying in refrangibility or attractive force. The solar electricity is seven-fold; the opposite is also varicolored, and I shall presently endeavour to shew, that it must in every thing correspond to the solar. There is nothing to lead us to believe, that the various colors or species of similar electricity have any union or attraction among themselves, or are otherwise connected, than as their similar tendencies produce similar, and therefore apparently joint effects, from the confusion and imperfection of our observation. Whenever their natures differ, we find each produce its effects separately and independently. The same variety of electrical force which causes the difference of refrangibility, and which produces the colored rings from a white ray, piercing a plate of air between two surfaces of glass, must cause the same difference in the intervals at which the various electricities are arranged in bodies at rest, the most refrangible, or those of greatest electrical force, having the greatest intervals or divisions.

sions. In elastic bodies, as the atmosphere, where the grosser matter is thinly scattered through the mass of electricity, this effect must be most strong.

THE truth of this reasoning seems to be established by attending to a very singular coincidence in nature, hitherto not satisfactorily accounted for ; the exact proportion between the refrangibility of the colors, and the notes of a musical octave ; the most refrangible corresponding to the deeper notes or larger vibrations of the music. It is impossible to believe that this coincidence is accidental, and the rules of philosophy compel us to conclude, that the same power produces both the effects. I suppose it to result from the arrangement of the electricities in the air, according to their colors or refrangibility.

A SOUND is the vibration of the air, carried along by the elasticity of the electric fluid in regular undulations, which may be considered as artificial divisions of the atmosphere.

mosphere. Its natural and permanent divisions are those produced by the arrangement of the differently colored electricities. When the vibration or artificial division coincides in space with any one natural division, or any regular number of intervals of one electricity, the sound or vibration will be regular, even, and melodious. This is a musical note. If the vibration be increased in length, so as to include the same number of intervals formed by the next color in frangibility, the next musical note is founded. When the vibration is increased so as to include double the number of intervals of the same electricity as the first, the octave of the first note is produced; being performed by the same electricity, the sounds are perfectly homologous *.

LIKE

* Probably the intervals or divisions of the electricities in the air are very small, and there may be many such in every artificial division by a musical vibration. The different numbers of those intervals in each vibration, probably mark the distinction of the different keys in music. The key A. may contain 9. 18. 36. &c. the key B. 8. 16. 32. &c. of the natural divisions in each vibration. Thus the

LIKE every other material object, the eye and optic nerve must be filled with electricity, separated into divisions alternately viureous and refinous, of each color, and must be susceptible of having their electricity excited, or arranged in a new and unusual manner, by the application of foreign electricity. Hence we must conclude, that

the same note may coincide with different keys. For if a vibration include 8 divisions of one electricity, it will also coincide with 9 intervals of another, whose refrangibility is to that of the first, in the proportion of 8 to 9, and so be in harmony with a key including 8, or with one including 9 natural divisions in each vibration. From the number of different colors by which any sound may be carried along, probably arise the distinctions of flat and sharp notes, and all the varieties in harmony.

The refrangibilities of the different colored electricities are in certain proportions, which will correspond at the following intervals. The violet, the most refrangible, will include in 9 of its divisions, 8 of indigo; in 5, 6 of blue; in 3, 4 of green; in 2, 3 of yellow; in 3, 5 of orange; in 9, 16 of red; in every division, two of its own octave. Men acquainted with music may, perhaps, carry very far the investigation of the consequences of these coincident proportions upon harmony.

the differently colored rays must operate upon the optic nerve according to their refrangibilities or electrical forces, separating its electricity into divisions of various dimensions. This different arrangement, and consequent various tension of the nerve, is probably the origin of the sensation of color, and therefore of all vision. Accordingly, we find that any other electrical affection of the optic nerve, as the application of common electricity, or of what is called animal electricity, produces the same sensation with light. The same effect is imitated by a blow or pressure upon the eye, expanding or contracting the nerve.

THIS explanation of the nature of vision, and the sensation of color, will account for the exact, and evidently more than accidental coincidence in the different colors of the opposite electricities. For as electricity of any color is in its distribution alternately vitreous and resinous, the one of these must occur in the same space as often as the other, and produce equal distribution of the electricity

tricity of the eye or other body upon which they act; this must produce equal arrangement and tension of the optic nerve, in which I suppose all sensation of color to consist. It is therefore scarcely material to inquire, whether the opposite electricities are naturally divided into similar colors or species mutually corresponding in force, or whether the one only is so divided, and the other is compelled by attraction, to assume the same arrangement to correspond to and balance each division of the first. The effect must be the same upon either hypothesis.

I HAVE thus endeavoured to trace the general outline of connexion between heat, light, and electricity; and hope to have shewn that the two former are only different actions of the latter power. It were beside the purpose of this essay, already sufficiently multifarious, to examine the abstract causes of that attractive force of electricity by which these various phænomena are produced, and to explore the whole properties

perties and effects of this wonderful fluid. To follow it in all its shapes, and scrutinize all its operations; to trace it as the general parent of attraction, producing that gravitation which arranges the universe into order, and giving, by its balanced force, that *vis inertiae* which seems almost the essence of matter; to paint it as the most powerful, most universal agent of the Almighty Creator, is for me too arduous a task. We know not how far the industry of future ages may raise the structure of human knowledge. My ambition is satisfied, in hoping that I have added one stone to the fabric, or arranged and cemented some loose and confused materials of the pile.

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